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Activity 3.7
Design technology solution for KACs

Deliverable 3.7.4
Report on the GUI/HMI implemented for the Virtual Diving system

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Deliverable Team: UNICAL, OC-UCY

Summary

1. Introduction

The Activity 3.7 “Design technology solution for KACs” and the respective deliverables include reports on the different technologies that will be employed for the development of the Virtual Diving Service deployed in KACs. Specifically, deliverable D3.7.4 reports the results of the implementation of the Graphical User interface (GUI)/Human-Machine Interface (HMI) of the system.

The Virtual Diving system combines the advantages offered by the recent advances in Virtual Reality (VR) technology with the newest 3D reconstruction techniques to create virtual tours for the exploitation of the Underwater Cultural Heritage. In fact, it represents an innovative solution that overcomes the limits imposed by the underwater environment and offers to the general public a playful and educational experience, by diving into faithful and realistic reconstructions of submerged archaeological sites.

The creation of the virtual scene described in section 2.2 has been obtained using the data acquired during the *in situ* activities that UNICAL, as responsible of the Capo Rizzuto pilot site, has carried out in the underwater archaeological site of Cala Cicala. The results of this work have been presented in Deliverable D3.4.2.

2. VR system Overview

The VR system is a virtual diving exhibit that allows users to explore the 3D reconstruction of the underwater site and receive historical and archaeological information about the submerged exhibits and structures of the site, but flora and fauna are also described, with a particular attention on their interaction with the submerged artefacts. The VR system can be also being used by diver tourists because of its capability to make a detailed planning of the operations, and of the itinerary to carry out in the underwater archaeological site. The system indeed represents a reliable instrument to plan and simulate the tourist itinerary that is performed at a later time in the real submerged environment. The VR system presents two different versions, each one characterized by the type of devices, the provided levels of immersion, interaction, and presence: the VR semi-immersive and VR immersive experiences. In the first one, users can perform a semi-immersive visualization by means of a full HD monitor that is based on passive 3D technology. Users interact with the system by means of a multi-touch screen tablet, featuring a user-interface that provides all of the input functionalities that are needed to explore the 3D environment and get access to the multimedia data. The visualization can be performed also in an immersive environment by means of Head Mounted Display (HMD) technology.

2.1 Software Architecture

The software architecture of the VR system is depicted in Figure 1. It consists of five main elements: a database, a web service, a scene editor module, a visualization module, and the controller module.

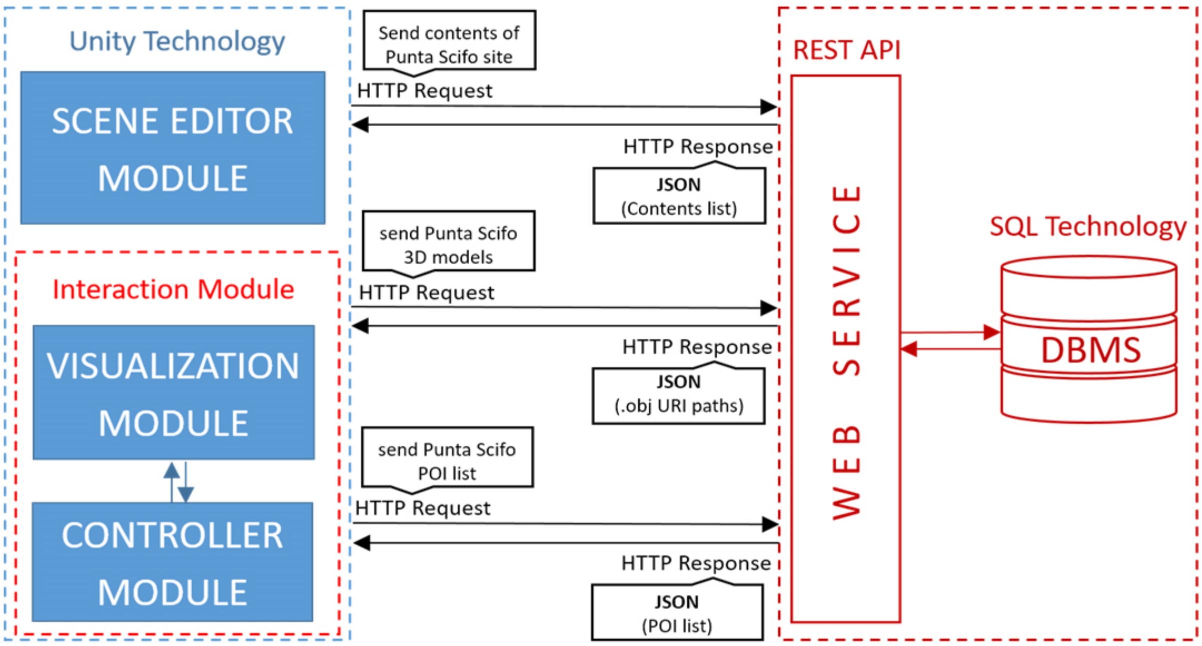

Figure 1 Software architecture of the VR system.

In particular, the SQL database manages all the data of the virtual scene. The web service provides a bilateral communication between the database and the other modules by means of a http protocol. The scene editor, visualization and controller modules have been implemented by means of the cross-platform game engine Unity. Thanks to the adoption of the Unity framework these modules can be used directly via web and can communicate, by means of the web service software, with the database for data uploading and downloading. The scene editor module allows to compose the virtual scene by integrating 3D objects and multimedia information stored in the database. Once the scene is created the interaction module is adopted to implement the logics of the virtual scenario defining the physics and behaviours of the elements that belong to the virtual environment. Furthermore, it loads from the database the graphical assets of the submerged, terrestrial and aerial environments, such as, refractions, fog, caustics of the particulate, etc. The interaction module allows to perform the exploration within the virtual scenario according to the user input by means of the controller.

2.2 Virtual Scene Creation

The 3D reconstruction of underwater archaeological assets requires attention because of the long and articulated process. One of the main scientific results of UNICAL concerns the integration of optical and acoustic techniques for the generation of multi-resolution textured 3D models of underwater archaeological sites. The proposed method exploits the high-resolution data obtained from photogrammetric techniques (Bruno et al., 2010; Bruno et al., 2011; Bruno et al., 2016a; Bruno et al., 2016b; Bianco et al., 2013) and the latest techniques for the construction of acoustic micro bathymetric maps (De Alteriis et al., 2003; Passaro et al., 2013) to build 3D representations that combine the resolution of optical sensors with the precision of acoustic bathymetric surveying techniques. The method allows for obtaining a complete representation of the underwater scene and to geo-localize the optical 3D model using the acoustic bathymetric map as a reference. For the scope of the project high frequency multibeam equipment has been adopted to obtain an acoustic bathymetry of the seabed with a sample spacing of about 3 cm; while photogrammetric techniques have been used to build a textured 3D model of the archaeological remains with a sample spacing of about 3 mm. In particular, after a first inspection of the site, the photogrammetric acquisition process is performed according to standard aerial photography layouts that consist of overlapping straight lines and also cross lines with oblique poses to minimize the occluded areas. Opto-acoustic markers, placed on the seabed and whose number depends by the extension of the site, are used to accurately compute the registration between the optical and acoustic point clouds. While, a set of triangular target are adopted to scale the 3D model. The last steps of the process consist of meshing and texturing the opto-acoustic point cloud of the underwater archaeological site. The meshing step is carried out using dedicated software, which has the ability to create a mesh by using an efficient multi-resolution algorithm and to perform further refinements of the model by using the point cloud as reference, so that the model reconstruction is performed in a coarse-to-fine fashion.

During the optical and acoustic survey activities, various useful and interesting locations are also defined and geolocated in order to be subsequently implemented as Points of Interests (POI)s in the virtual reproduction of the underwater archaeological site. In fact, once the creation of the textured 3D model of the underwater archaeological area is achieved, it is adopted as starting point by the web editor module to build and assemble the immersive environment (Figure 2).

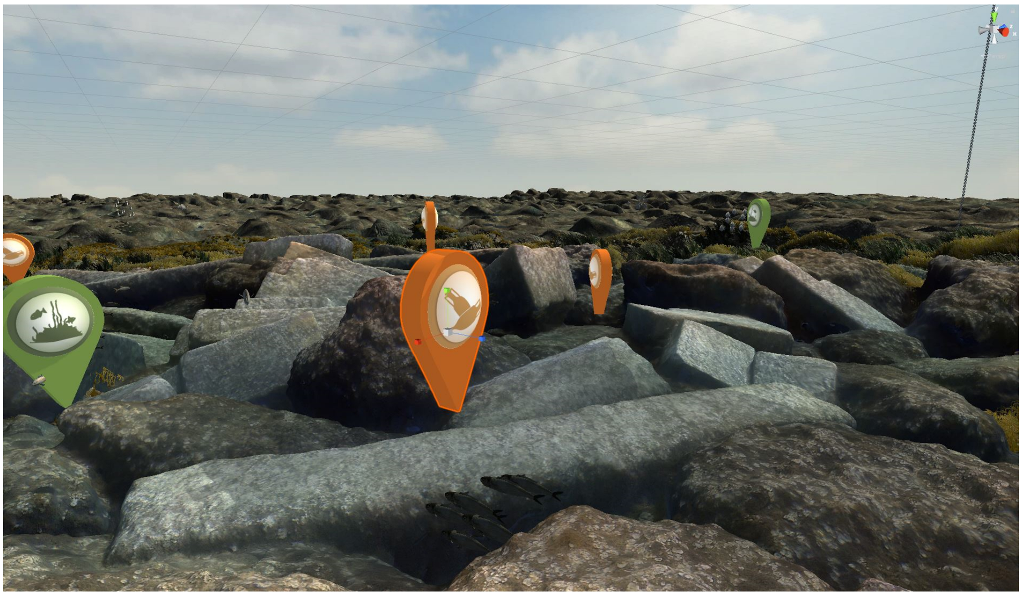

Figure 2 Adding a 3D object of a POI in the virtual scene.

In particular, the virtual scene is populated with 3D models of the flora and fauna typical of the specific marine ecosystem, such as fishes, sponges, seagrass and seaweed plants. The POIs are added to the virtual scene in form of 3D large head map tips whose colour depends by the category they belong to, e.g. yellow for the historical and archaeological information and green for biological ones. As depicted in Figure 3, 3D models of fishes and schools of fish, typical of that site, are settled into the underwater environment and animated by means of artificial intelligence techniques. The vegetation is placed exactly as it was captured during the optical survey and it is reproduced by means of texture effects that mimic the movements of the real plants.

Figure 3 Reconstructed archaeological site with 3D POIs, flora and fauna.

2.3 Semi-immersive Virtual Reality environment

The semi-immersive setup of the VR system has been designed on the basis of a user-centered design (UCD) (Barbieri et al., 2017) by evaluating different embodiments, such as monitors and projectors for the visualization and touch-screen consoles and trackballs for the interaction. After an accurate evaluation of the pros and cons of the different solutions, an HD monitor and a multi-touch tablet have been adopted for the user interaction and exploitation of the virtual diving. About the touch-screen remote control it could be a handheld device, i.e., tablet, or fixed in a specific position (Figure 4). The first solution can usually be adopted when an operator stands over the system. Instead, the second solution can be employed when the system is intended for unattended operation and, since the console cannot be moved, it is possible to increase the screen size of the touch-screen to enhance its legibility.

Figure 4 Semi-immersive VR system with a handheld device (left) or a fixed remote control (right).

The 3D HD monitor is based on passive technology. It has been preferred to the active one because passive 3D glasses are lighter and more comfortable than active glasses which, on the contrary, are expensive and need batteries to work.

The user interface displayed on the touch-screen console provides all the input functionalities needed to explore the 3D environment and to get access to the multimedia data. In particular, the UI features two large command buttons, respectively, to go back and forth and to rotate the camera's point of view. On the top left side of the UI, a slider controls the depth of the camera view from the water surface. While, on the top right side, two circle buttons allow the user to switch between two different exploration modalities: guided tour modality and free navigation mode.

When the user approaches a POI element the UI displays a visual warning and, at the same time, provides two command buttons that allow to question or skip it. In the first case, a new window appears in the centre of the UI containing textual, graphical and audio information related to the specific POI (Figure 5).

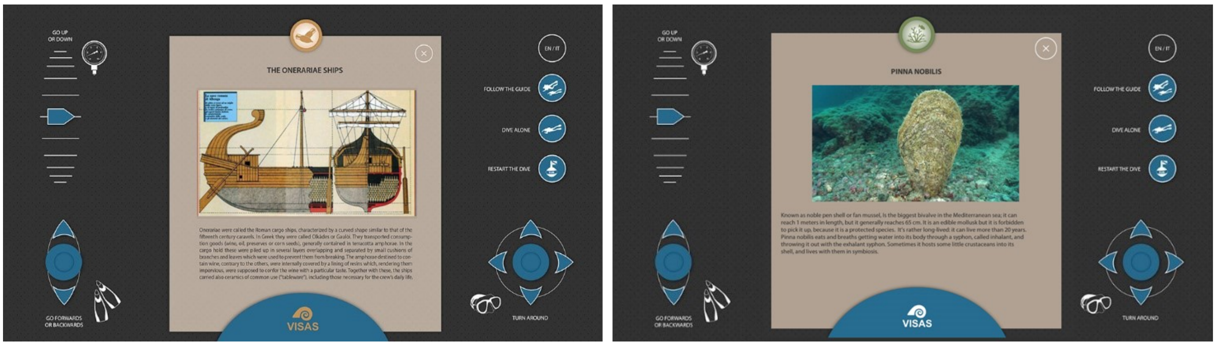

Figure 5 Multimedia data appear on the touch-screen console when questioning POIs.

The game logic design of the semi-immersive VR environment has been developed according to the best practices related to the gamification design process (Wei and Li, 2010; Kapp, 2012; Morschheuser et al., 2017) to maximize enjoyment and engagement through capturing the interest of learners (Huang and Soman, 2013). The exploration of the underwater archaeological site starts above the water surface in the diving spot (Figure 6). In order to make a more attractive and engaging experience, the terrestrial environment has been added and constructed in the most realistic way possible. The buoy and the inflatable boat have been added to the virtual scene, as well as the stretch of coastline that overlooks the diving site.

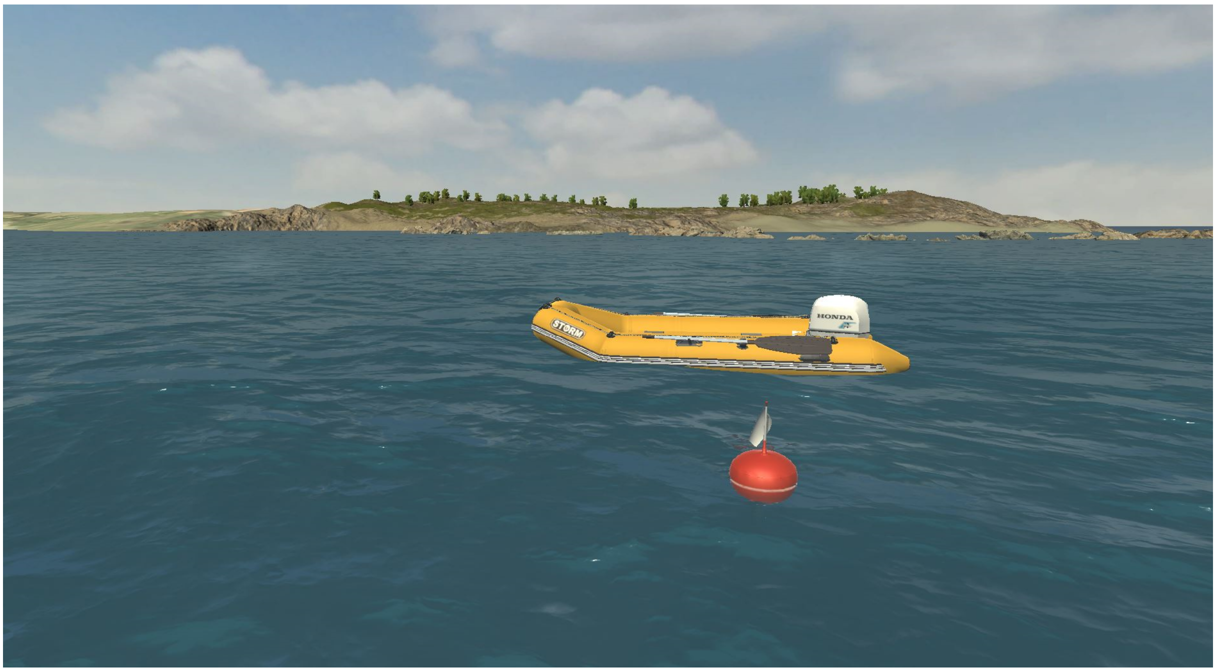

Figure 6 Diving spot of the virtual session.

Once the user dives in the submerged virtual environment, he/she is guided by a directional 3D arrow toward the archaeological site. The exploration can be performed in two different modes that can be selected by the user on the UI: free or guided tour. In both cases the player is engaged into an active state of learning where he/she is motivated to create his/her own knowledge rather than to receive information passively. In particular, in the first mode, the user can dive freely in the archaeological area and he/she is free to pick the desired POI or simply take an overview of the submerged area. In the other case, the guided tour mode features a virtual diver who guides the user during the exploration of the underwater archaeological site (Figure 7). In particular, the virtual diver implements a logical follow-on of the POIs that, according to a storyline approach, allows users to follow one or more itineraries and 'themed' routes. In the guided tour mode, the 3D POIs are hidden and they become visible, one at a time, when the scuba guide moves closer to them. At that point, the user can decide to skip the POI and pass to the next one, or to activate it and receive specific information by means of multimedia content (audio, video, and text).

Moreover, the guided tour modality allows users to simulate a real diving session taking into account the shortest path to safely visit the POIs of the underwater sites. The scope is to raise awareness of the time constraints and human body's limitations, arising from scuba diving related problems, typical of the underwater environment. This modality has been implemented developing a pathfinding algorithm that: recognizes obstacles within the 3D environment; generates the shortest paths through the POIs avoiding obstacles and minimizing the pressure at which the diver is subjected; verifies the generated paths' admissibility according to constraints (the air in the diving cylinder and the decompression stops) imposed by the underwater environment.

Figure 7 Scuba guide for the exploration of the underwater archaeological site.

2.4 Immersive Virtual Reality environment

The immersive diving environment is built by means of HMD technology in order to provide to its users a total immersive experience of the underwater archaeological site. This technology in fact allows for achieving the best results in terms of immersivity because it absorbs completely the users in the virtual environment. The light-weight helmet isolates the user from the distractions of the actual physical environment and encompasses the entire field of view, including the peripheral space. It contains a high-resolution stereoscopic display; adjustable optics (usually based on Fresnel lenses); an optical tracking system capable of tracking both the position and the orientation of user's head and, usually, a stereo audio output. Most of the products currently available on the market still require a cable connection to the computer because the very high demand on data throughput, image latency and power consumption.

The HMD is usually coupled with one or two wireless handheld controllers for a better experience in the VR environment. Each controller is equipped with several buttons, joystick or touchpad as a means of human-computer interaction. They could also be tracked in terms of position and orientation in 3D space. The use of this configuration (HMD and a pair of tracked controllers) provides a very immersive and natural interaction with virtual worlds; user can freely walk and look around, reach out their hands and interact with virtual objects.

The immersive VR system has been developed in Unity for the HTC Vive VR headset (Figure 8). In particular, the HTC Vive features a resolution of 1080x1200 per eye, 90 Hz refresh rate, and a field of view of 110°). Furthermore, it comes bundled with two motion tracked controllers and laser based tracking system called Lighthouse, providing 6 DOFs tracking in an up to 4.5 m x 4.5 m area with two beacons.

Figure 8 Immersive VR system.

When the user wears the HMD he/she experiences the immersive virtual environment from the scuba diving viewpoint simulating a real diving session. The scenario that appears at the beginning of the virtual experience is above the water surface in the diving spot. Once he/she dives in the submerged virtual environment, he/she is guided by a directional 3D arrow to the archaeological underwater site. When he/she arrives to the site the 3D arrow disappears and lets him/her free to interact with the 3D POIs to discover historical and archaeological information. The user interaction is focused on navigating inside the virtual environment and receiving information about the archaeological and biological assets. He/she navigates in the virtual environment by moving his/her head and interacting with the virtual scene using the wireless handheld controllers. Through the input devices, the user instructs the software about the desired orientation and direction to follow for exploring the submerged virtual area. During the navigation, the controllers are mainly used for directional inputs for exploring the virtual underwater environment. Nevertheless, when the user reaches a POI, this needs to be enabled to get access to its multimedia contents. In the immersive environment, the POIs are enabled directly by the user, by pointing and selecting them by squeezing the hair trigger of the handheld controller. In this case, the multimedia contents are displayed within the virtual scenario into a 3D frame (Figure 9).

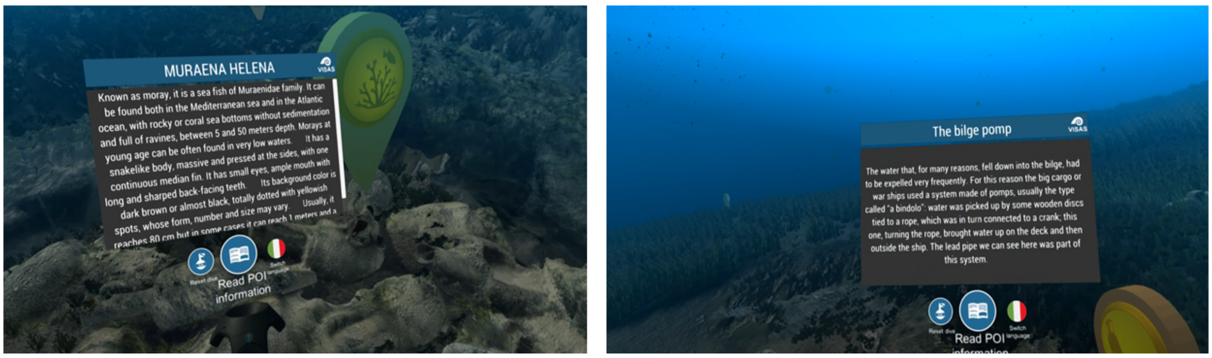

Figure 9 Archaeological asset description.

3. User study

A preliminary study on the user experience related to the semi-immersive and immersive environments (Barbieri et al., 2017) have been carried out at the Department of Mechanical, Energy and Management Engineering (DIMEG) of the University of Calabria (Italy). In particular, a comparative user study has been performed for evaluating the usability and enjoyment provided by the two different environments. The minimum number of participants has been defined on the basis of the most influential articles on the topic of sample size in user studies (Dumas et al., 1995) adopting a problem discovery rate of 95%. This value has been adopted as a threshold to deploy participants among the groups. Nevertheless, as many users as possible have been involved in the test in order to collect a greater number of feedbacks and personal opinions.

Four representative user groups (Figure 10), divided by age, have been involved in the comparative study:

- G1: 28 preteens from 10 to 13 years old (mean=12 - standard deviation=0,82);
- G2: 24 teenagers from 14 to 16 years old (mean=14,83 - standard deviation=0,76);
- G3: 18 male young adults from 17 to 22 years old (mean=18,11 - standard deviation=1,23);
- G4: 31 female young adults from 17 to 24 years old (mean=18,06 - standard deviation=1,21).

Figure 10 Participants of the user study while interacting with the semi-immersive and immersive environments.

The comparative procedure consisted of three main steps. In the first step, after a short presentation of the virtual diving system, a quick demo of its main features and of the different user interactions in the semi-immersive and immersive environments have been shown to the participants. In the second step, each participant performed a free exploration of both environments without any limitation in time. By the end of the second step, users have been invited to fulfil a satisfaction questionnaire and to perform a one-on-one personal interview aimed to comprehend their enjoyment and catch all their possible personal judgements. The satisfaction questionnaire has been developed on the basis of standard questionnaires based on psychometric methods (Lewis, 2006) whose items' evaluation can be expressed by users by means a 7-point graphic scales (Likert scale), anchored at the end points with the term "Strongly disagree" for 1 and "Strongly agree" for 7.

The user satisfaction questionnaire results revealed that both the semi-immersive and immersive environments of the VR system gained similar levels of learnability, efficacy, and enjoyment. These levels reached high values in all the groups with a minimum score of six out of seven. In particular, little differences in subjective opinions between the semi-immersive and the immersive environment have been observed in each group and among the groups. But, statistical analysis, based on t-test and ANOVA techniques, revealed insufficient evidence to confirm these small gaps. Differently from the user satisfaction questionnaire results, when participants were asked to express their preference, the vast majority of them clearly expressed their choice, as depicted in the following figure, for the immersive environment and consequently for the HMD device.

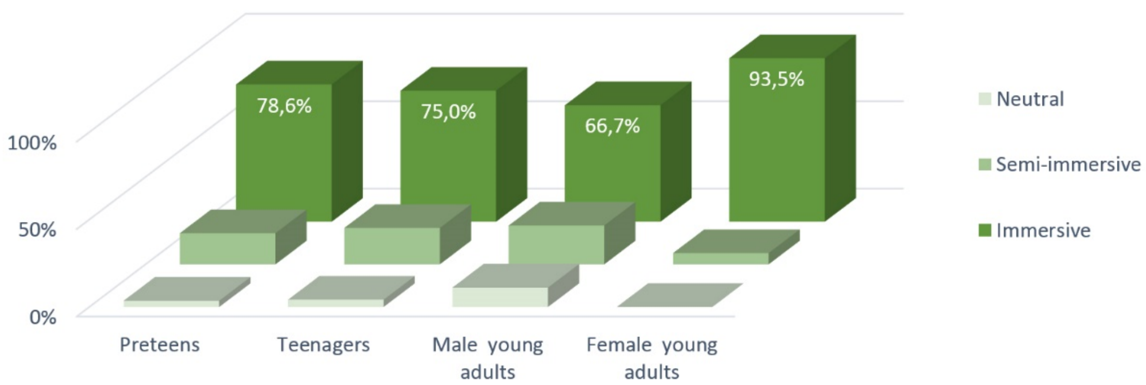

Figure 11 Subjective preference results.

This result has been unexpected because even if all the users were confident in the use of 3DTV and multi-touch devices, only few of them had previous experience in the use of HMDs. In the one by one interviews, the subjects justified their preference asserting that, even if they felt comfortable in the adoption of 3DTV, the HMD technology provided a much more immersive virtual experience and allowed them to behave in a more natural way: in fact, they were able to turn their heads or their whole body naturally.

In conclusion, on the basis of this user study, the semi-immersive and the immersive environments provide to the user's high equivalent levels of usability and enjoyment. Then, the level of the immersion of the VR system can be choice according to factors related to the specific application context or to subjective preferences rather than usability metrics. In fact, as emerged from the participants' personal interviews, the HMD technology is an appropriate choice especially when users need to make frequent turns to look around and enjoy of the virtual environment. On the other side, the semi-immersive environment could be more adequate for museum and school contexts in which there is the need to make the virtual experience available to a large number of visitors or to allow a shared exploitation of the virtual scenario to more than one person at a time.

4. Conclusions

This report has presented the virtual diving system for the exploitation of the Underwater Cultural Heritage. This VR system allows users to live a virtual experience inside the reconstructed 3D model of underwater archaeological sites and explore the various and different POIs that populate the archaeological area by means of a free or guided tour.

The VR system has been designed to entertain users but its added pedagogical value is explicitly emphasized too. In fact, the ludic activity, consisting in the simulation of a real diving session from the point of view of a scuba diver, is combined with the educational purpose by means of a storyline approach based on a virtual scuba diver that guides the user among the various POIs that populate the underwater site. When activated, POIs offer specific information about historical and archaeological peculiarities; flora and fauna are also described with a particular attention on their interaction with the submerged artifacts. The user study has demonstrated that both the semi-immersive and immersive environments present high levels of usability and enjoyment for all the categories of participants, which differ for age and sex. Since the user studies have been carried out among teenagers and young adults, further usability tests will be performed recruiting adult and elder participants too. Furthermore, the transmission of knowledge to the user, after having experienced the virtual diving environment, will be explored to assess the learning benefit of the system.

5. References

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